

Article

A Low-Cost Head-Controlled and Sip-and-Puff Mouse: System Design and Preliminary Findings

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Abstract

This work introduces a low-cost, wearable assistive mouse designed to support digital interaction for individuals with motor impairments. The system combines inertial sensing for head-movement tracking and a pressure-based interface for simulating mouse clicks via “sip-and-puff” actions. The device enables full mouse control (pointer movement, clicks, and double-clicks) without relying on hand mobility. Preliminary evaluations, conducted with input from occupational therapy professionals, demonstrated promising usability and functionality comparable to commercial devices. The proposed solution offers a cost-effective, open-source alternative to existing adaptive technologies, with future development aimed at broader testing and integration in rehabilitation settings. Future work will include usability testing with individuals presenting real motor impairments to validate clinical applicability.

Keywords: assistive technology; motor disabilities; accessibility; head tracking; inertial measurement unit; pressure sensor; sip-and-puff; adaptive mouse; digital inclusion; Bluetooth Low Energy



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1. Introduction

Access to digital technologies is essential for participation in modern society. From communication and education to employment and healthcare, daily activities increasingly rely on computers and internet-enabled devices. However, for individuals with motor disabilities, interacting with such technologies can be severely restricted, particularly when traditional input devices like a mouse or keyboard are not accessible. This digital divide contributes to social and economic exclusion, reinforcing existing inequalities.

Assistive technologies (ATs) aim to address these challenges by offering alternative input modalities. Devices based on head tracking, eye movement, or breath control (“sip-and-puff”) have shown considerable promise in enabling users with physical limitations to interact with digital environments. Nevertheless, existing solutions often present significant barriers: they can be expensive, lack integration between multiple input methods, or offer limited adaptability for different user needs [1].

Various commercial products have emerged to tackle specific use cases. For instance, gyroscopic mice like the Quha Zono [2] allow head movement to control the cursor, while devices such as the Breeze convert air pressure into binary input. Hybrid solutions like the FlipMouse [3] combine multiple sensors, but typically require technical knowledge

or funding that many users do not have. Moreover, some systems are not open-source, limiting customization and broader community-driven development.

Despite increasing interest in ATs, there still remains a need for low-cost, flexible, and fully integrated devices that can deliver full mouse functionality (pointer movement and clicking) through alternative input mechanisms while maintaining ease of use and broad platform compatibility. This is particularly relevant in educational or home settings, where professional technical support may not be available.

In this context, the present work proposes the development of a wearable adapted mouse that combines a head-mounted inertial measurement unit (IMU) for cursor movement with a pressure sensor for click control via “sip-and-puff” actions. The system is built with low-cost electronic components, communicates wirelessly via Bluetooth Low Energy (BLE), and features a modular architecture to facilitate future customization. Preliminary testing was conducted with feedback from occupational therapy professionals, and the device was benchmarked against a commercial product.

Unlike existing commercial or research alternatives, the proposed solution prioritizes low cost, open hardware and software, wireless compatibility, and modularity to facilitate further customization by rehabilitation professionals and makers. The central research question addressed is whether an IMU and pressure-sensor-based system can deliver a reliable and intuitive full mouse functionality for users with limited or no hand mobility.

The results suggest that the proposed solution can provide a viable, affordable, and customizable alternative to existing commercial systems. This contribution aims to support digital inclusion, especially for users in low-resource contexts, and serve as a foundation for future research and development in accessible human-computer interfaces.

2. Related Work

Assistive pointing devices have been extensively investigated in both academic research and commercial product markets, driven by the need to provide computer access to individuals with upper-limb impairments, neuromuscular conditions, or limited fine-motor control. Existing solutions rely on a wide range of sensing modalities, including head orientation, breath pressure, electromyography, capacitive touch, and vision-based tracking, each exhibiting distinct advantages and trade-offs in terms of cost, ergonomics, latency, and required user mobility. Academic prototypes typically explore novel interaction paradigms, emphasize low-cost hardware, and prioritize customizability for rehabilitation contexts, while commercial devices focus on robustness, integrated support, and long-term usability. This section provides an overview of relevant academic and commercial assistive technologies, highlighting their key characteristics, strengths, and limitations as a foundation for contextualizing the system proposed in this work.

2.1. Academic Assistive Devices

Head-orientation-based pointing remains one of the most widely investigated modalities in assistive human-computer interfaces. Early work employed webcam-based template tracking to follow visible facial features such as lips or nose [4], enabling continuous cursor movement combined with dwell-time selection for clicks. Later solutions integrated inertial measurement units (IMUs) mounted on the head, providing absolute orientation detection with low latency and independence from lighting conditions [5]. Optical reflective tracking approaches using infrared illumination and a reflective target attached to a cap have demonstrated robustness and minimal calibration requirements [6]. Wearable eyeglass-mounted IMU systems have also been proposed, combining head rotation with optical blink detection to enable both pointer movement and click activation [7]. Head-orientation devices

generally provide intuitive control and high learnability, but require preserved cervical mobility and exhibit reduced throughput when selecting small, high-precision targets.

Breath-activated interaction constitutes an alternative when upper-limb mobility is severely impaired. Campos et al. [8] demonstrated that puff-based activation achieved faster task execution and higher subjective satisfaction than dwell-based clicking. More hardware-centric designs use arrays of electret microphones to classify short and long blow durations [9], enabling continuous pointer travel, dragging, and scrolling without the need for digital signal processing. Breath-based devices offer intentional control with low fatigue and minimal muscle involvement, though sustained airflow performance varies across users, and careful sensor placement is required to avoid misclassification.

Electromyography (EMG)-based activation has been explored as a hands-free method for clicking. The contraction of frontal or facial muscles is detected via surface EMG electrodes, generating discrete click events [8]. This approach provides intentional activation and good timing precision but may cause long-term discomfort due to adhesive electrodes and cabling, as well as sensitivity to facial artifacts. Acceptability studies have shown that users generally prefer EMG over dwell-time methods, although setup complexity and calibration remain barriers.

Vision-based head-controlled systems leveraging machine learning have emerged as an additional alternative. Abiyev and Arslan [10] proposed a camera-based solution that employs Haar cascade classifiers and convolutional neural networks (CNNs) to classify head directions and eye states, enabling cursor movement and clicking without wearable hardware. These systems reduce physical burden and improve comfort, but are highly dependent on lighting conditions, camera quality, and computational resources.

Multimodal devices aim to broaden applicability across heterogeneous disability profiles. Bacelar et al. [11] presented a configurable system that combines IMU-based tilt sensing, gesture recognition, capacitive switches, and auxiliary buttons. The device can be attached to various body locations and tuned via adjustable thresholds to mitigate tremor or involuntary motion. Specific implementations have sought to optimize this multimodal fusion for cost and specific user needs.

Elder et al. [12] developed a prototype specifically for quadriplegia that fuses a headset-mounted 9-DoF IMU (MPU-9150) for cursor navigation with a sip-and-puff pressure transducer (MPX12GP) for click actuation. By processing sensor data via an Arduino Due to emulate standard USB HID protocols, they achieved a low-cost (<\$130) alternative to commercial trackers. However, their work also highlights the engineering challenges inherent in multimodal integration: while the head and breath systems were successful, the attempt to map secondary control keys to shoulder-mounted accelerometers was abandoned due to timing unreliability and computational complexity. Multimodality increases flexibility and inclusion, but introduces configuration complexity and longer personalization sessions. Our work follows the same general principle (leveraging sip-and-puff signals for clicks/selection, combined with a non-traditional pointer control), but differs in several important aspects. First, our device is fully wireless, eliminating the need for any wired interface connection. Second, our design emphasizes affordability and open-source hardware and software, aiming to deliver a low-cost solution that supports broader adoption.

In addition to pointer-centric interaction, tactile spatial feedback has been explored as a complementary accessibility channel. Sait et al. [13] developed a haptic glove that vibrates in response to proximity to the screen boundary and icon hover events, providing spatial cues for blind users navigating a desktop interface. Combined with speech-based mobile interaction, this approach reduces the need for sequential exploration and improves robustness to application crashes. These tactile methods expand accessibility beyond motor impairment but require wearable hardware and proper fit for vibration localization.

Finally, recent work has begun to examine the acceptability of wearable head-mounted controllers from a behavioral perspective. Kabir et al. [14] applied the Technology Acceptance Model (TAM) to a wireless IMU-based assistive mouse and reported high perceived usefulness, ease of use, and adoption intent among stroke survivors, despite initial technology anxiety. This highlights that real-world adoption depends not only on technical performance but also on psychological constructs such as confidence, social influence, and personal innovativeness.

Table 1 summarizes selected academic solutions based on their main characteristics.

Table 1. Summary of representative academic assistive interfaces and their main modalities, advantages, and limitations.

Study	Modality	Key Features	Limitations
Betke et al. [4]	Vision (webcam facial tracking)	Non-contact, intuitive control via visible facial features; early optical approach to continuous cursor control	Sensitive to lighting and camera quality; potential latency on low-end hardware
Raya et al. [5]	IMU (head orientation)	Lighting-independent absolute orientation sensing; low latency; simple wearability	Requires preserved cervical mobility; reduced precision for small targets
Pereira et al. [6]	Infrared reflective tracking	Robust tracking with IR illumination and reflective marker; minimal calibration	Needs external camera + marker; line-of-sight constraints
Machado et al. [7]	IMU + optical blink	Combines head rotation for pointer with blink detection for click; integrated selection method	Blink detection can be error-prone; potential user fatigue/eye strain
Campos et al. [8]	Puff / EMG / dwell (comparison)	User study shows puff-based activation is fast with high satisfaction; direct comparison of click methods	Dependent on respiratory strength or electrode placement; setup/calibration overhead for EMG
Chen et al. [9]	Acoustic blowing sensor (puff)	Simple hardware using microphones to classify short/long blows; supports drag/scroll without complex DSP	Can be affected by ambient noise; requires consistent airflow control
Abiyev & Arslan [10]	Vision + ML	No wearable hardware; CNN-based classification of head direction and eye state; comfortable for users	High computational demand; sensitive to lighting/camera quality
Bacelar et al. [11]	Multimodal (IMU + capacitive + buttons)	Highly configurable; adjustable thresholds mitigate tremor/involuntary motion; adaptable mounting locations	Greater configuration complexity; longer personalization time
Elder et al. [12]	Multimodal (IMU + Sip-puff transducer)	Head-mounted IMU; Sip-puff for clicks; Low-cost Arduino microcontroller; Multi-platform	Accelerometer reliability issues; Single user testing; No commercial viability; Input latency; Comfort not fully tested

Table 1. Cont.

Study	Modality	Key Features	Limitations
Sait et al. [13]	Haptic glove (tactile feedback)	Vibrotactile cues for spatial awareness (boundaries, hover) support navigation and robustness	Requires additional wearable hardware; correct fit needed for clear localization
Kabir et al. [14]	IMU + user-acceptance (TAM)	High perceived usefulness/ease-of-use among stroke survivors; behavioral perspective on adoption	Short-term evaluation; limited evidence on long-term use in daily living

In summary, the academic literature demonstrates a broad spectrum of interaction modalities that support users with severe motor impairments. Head-orientation devices offer intuitive pointing but rely on neck mobility; breath-based systems require minimal muscular input but depend on respiratory control; EMG enables intentional activation with good precision but introduces sensor-wear discomfort; vision-based approaches reduce physical burden but depend on environmental conditions; multimodal systems maximize adaptability at the expense of configuration complexity; and tactile feedback expands accessibility for visually impaired contexts. Across modalities, two limitations consistently persist: limited long-term validation in daily living environments and the predominance of evaluations with healthy volunteers rather than clinical cohorts.

2.2. Commercial Assistive Devices

One of the most widely adopted commercial solutions for hands-free cursor control is head tracking, typically implemented through inertial measurement units (IMUs) or gyroscopic sensors. The Quha Zono and Zono 2 are examples of head-mounted devices that enable pointer movement via subtle head rotations, providing wireless communication, configurable sensitivity, and compatibility across multiple operating systems [2,15]. However, prolonged neck rotation may induce fatigue in users with limited cervical mobility.

Another category of assistive devices uses air pressure input, commonly known as sip-and-puff systems. The Breeze sip-and-puff switch maps inhalation and exhalation to discrete mouse or keyboard events [16]. Open-source alternatives, such as the Analog sip-and-puff switch, offer adjustable pressure thresholds and integration via standard 3.5 mm switch interfaces, making them suitable for rehabilitation environments [17].

Hybrid devices aim to broaden accessibility across different impairment profiles. The FlipMouse, developed by the AsTeRICS Foundation, integrates sip-and-puff sensing with light-touch buttons and joystick-like directional control, providing both continuous cursor movement and click activation in a single platform [3].

Additional commercial solutions such as the Abili Head Mouse [18] and GlassOuse [19] also employ IMU-based head tracking and support Bluetooth communication, offering discreet, wireless access for users without residual hand mobility. These systems are typically worn on the head or mounted on eyeglasses, improving ergonomics and portability.

Despite recent advances, several limitations persist across commercial devices. Many options remain cost-prohibitive, often priced between €350 and €1000, restricting adoption in resource-constrained clinical or educational contexts. In comparison to these commercial solutions, the proposed device is a significantly more affordable option. The estimated cost of the current prototype is approximately €40, making it a low-cost alternative to products mentioned. Proprietary firmware and closed hardware platforms also limit customizability, reducing their suitability for research laboratories and personalized rehabilitation programs.

Furthermore, some devices focus exclusively on pointer movement and require external switches for click activation, increasing system complexity.

Table 2 summarizes selected commercial and open-source solutions based on their sensing modality and connectivity characteristics.

Table 2. Comparison of commercial and open-source assistive mouse systems.

Device	Head Movement	Pressure Sensor	Connectivity
Quha Zono/Zono 2	Yes	No (external only)	USB
Breeze	No	Yes	USB
Analog sip-and-puff	No	Yes	3.5 mm Jack
Abili Head Mouse	Yes	No	Bluetooth
FLipMouse	Partial (joystick)	Yes	USB
GlassOuse	Yes	No (external only)	Bluetooth

2.3. Comparative Discussion

Academic prototypes and commercial assistive devices exhibit complementary strengths and limitations. Academic systems typically emphasize technological innovation, cost reduction, and modality exploration. They often introduce new input methods, such as breath activation, surface electromyography, or multimodal gesture control, that broaden accessibility for diverse impairment profiles. Furthermore, academic designs often adopt open-source hardware and firmware, enabling rapid customization, parameter tuning, and integration with rehabilitation research. However, most academic prototypes are evaluated in short-term laboratory conditions with small cohorts, often involving healthy participants rather than clinical populations. As a result, long-term durability, ergonomic comfort, and reliability under daily usage remain insufficiently validated.

Commercial assistive devices, conversely, provide robust hardware, refined usability, and regulatory compliance through extended product development cycles. These solutions benefit from professional manufacturing processes, warranty support, and cross-platform compatibility. Devices such as IMU-based head mice and sip-and-puff controllers demonstrate stable performance in real-world contexts and are widely deployed in home, clinical, and educational environments. Nevertheless, commercial offerings tend to rely on closed software ecosystems and limited parameter configurability, reducing adaptability for atypical motor profiles. Their cost, frequently between €350 and €1000, constitutes a substantial barrier in resource-constrained settings, and many systems require auxiliary switches to support click activation, increasing complexity and mounting requirements.

In contrast to commercial products, academic contributions increasingly explore multimodality to address heterogeneity in motor impairment, combining head orientation sensing with EMG, capacitive buttons, or breath-based commands. While this improves inclusivity, the resultant configuration space may increase cognitive load and calibration time. Commercial devices prioritize consistent, low-friction onboarding at the expense of modality diversity. Furthermore, academic studies commonly investigate emerging sensing technologies and classification algorithms, whereas commercial devices prioritize stability and safety within established modalities.

Overall, the comparison suggests a persistent translational gap: academic innovations remain rarely transferred into durable commercial form factors. In contrast, commercial solutions often lag behind research in modality diversity and adaptive personalization. Bridging this gap requires collaborative efforts that combine the adaptability, affordability, and experimental breadth of academic work with the robustness, ergonomic refinement, and usability validation characteristic of commercial products.

3. System Architecture

The assistive device developed in this work enables hands-free control of a computer mouse by combining head-orientation tracking with pneumatic input, targeting users with limited upper-limb mobility. The system was designed to fulfil key functional requirements typical of assistive technology: low latency, low power consumption, ergonomic wearability, and compatibility with mainstream operating systems. Its architecture integrates an inertial sensor, a high-sensitivity pressure transducer, and a microcontroller that emulates a Bluetooth Human Interface Device (HID).

At the core of the device is the ESP32-S3, a microcontroller featuring integrated Bluetooth Low Energy (BLE), USB OTG support, and sufficient processing resources for real-time sensor acquisition and HID communication. Compared to previous ESP32 generations, the S3 variant enables native BLE HID emulation without additional adapters, reducing system complexity and physical footprint [20]. The controller also supports deep-sleep power modes, which are beneficial for battery-powered wearable applications.

Head movement is captured using the MPU6050 inertial measurement unit, which provides six degrees of freedom through a three-axis accelerometer and three-axis gyroscope [21]. Raw IMU measurements are sampled at 100 Hz and processed using a complementary filter to improve orientation stability and reduce high-frequency jitter.

Click actions are triggered by the LPS33HW pressure sensor, which can detect small differential pressure variations associated with sip-and-puff gestures. Its waterproof packaging, I²C communication interface, and high signal-to-noise ratio simplify integration and increase long-term reliability compared to mechanical pressure switches [22].

An overview of the hardware architecture is shown in Figure 1, which illustrates the interactions among the sensors, microcontroller, power subsystem, and output components. The system employs a rechargeable Lithium-Polymer (LiPo) battery, protected by a dedicated charge-management module and low-voltage cutoff circuitry to ensure safe operation. Status LEDs provide visual feedback during pairing and activation, while optional tactile buttons offer redundancy for users unable to generate stable pneumatic input.

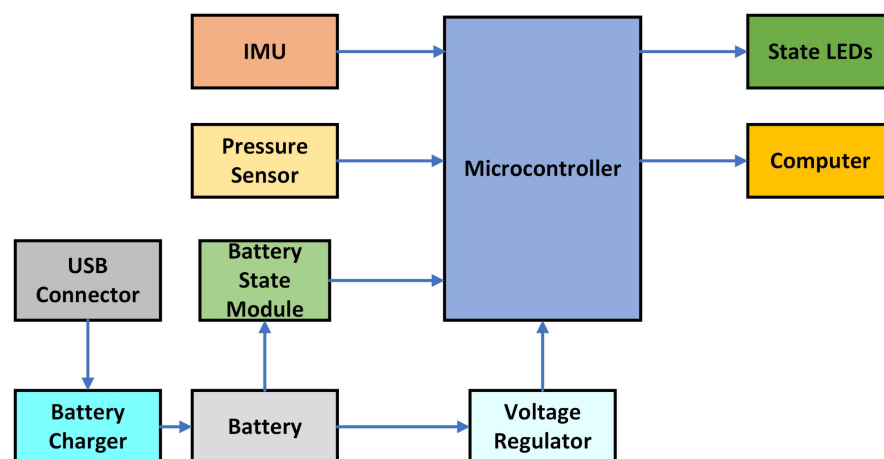


Figure 1. Block diagram of the assistive system developed, showing sensor inputs, microcontroller logic, and communication/output blocks. Diagram created by the authors.

Firmware is implemented using the Arduino framework, and communication with the host computer is performed using the BLE HID protocol. This ensures compatibility with modern operating systems without requiring additional software drivers or kernel modifications. Due to its modular design, the architecture can be extended to support additional sensing modalities, such as capacitive touch or eye-based interaction, or alternative wireless interfaces with minimal hardware redesign.

4. System Development

This section describes the implementation of the system's main hardware components, including the pressure sensor, the inertial measurement unit, and the custom-printed circuit board (PCB). The hardware design focused on modularity, electrical robustness, manufacturability in a laboratory environment, and ergonomic compatibility with users presenting reduced mobility.

4.1. Pressure Sensor

The system employs the LPS33HW pressure sensor due to its small form factor, high resolution, and waterproof housing, which is advantageous in prolonged breath-based interaction scenarios. The sensor communicates with the microcontroller through the I²C protocol and is mechanically coupled to a flexible plastic tube positioned near the user's mouth. Tube length and diameter were selected empirically to balance breath sensitivity, user comfort, and hygienic considerations.

In firmware, absolute and differential pressure thresholds are defined to detect intentional inhalation and exhalation while rejecting fluctuations from passive breathing and ambient airflow. To reduce false positives, a hysteresis window is applied to short-duration pulses, and a minimum activation time is enforced. Positive pressure (exhalation) generates a left-click event, whereas negative pressure (inhalation) triggers a right-click. This configuration enables users with minimal residual motor control to issue discrete selection commands without hand involvement.

4.2. Inertial Measurement Unit (IMU)

Head-orientation tracking is performed using the MPU6050 IMU, which provides three-axis gyroscope and three-axis accelerometer measurements. Data are sampled at 100 Hz and low-pass filtered to remove high-frequency jitter. The firmware monitors angular velocity along the pitch and roll axes; when values exceed predefined thresholds, the corresponding cursor movement is applied on the host system. A dead zone around the neutral position prevents unintended micro-movements from drifting the pointer.

A calibration routine is executed at startup to establish a neutral orientation and compensate for user posture variability. This approach mitigates unwanted drift resulting from non-uniform mounting or asymmetrical head positions. Pitch-based control was selected over Yaw-based tilting to reduce cervical fatigue and improve pointer reachability.

4.3. PCB Development

To integrate all components into a compact, reliable form factor, a custom two-layer PCB was designed in Altium Designer. Datasheet reference designs were followed to ensure correct electrical operation, and a ground plane was implemented on the bottom layer to reduce analog noise and simplify routing. Signal trace widths were chosen based on the expected current draw and impedance considerations: 0.6 mm for ground, 0.5 mm for power rails (3.3 V), and 0.4 mm for logic lines.

Fabrication was performed in the university electronics laboratory, subject to constraints on minimum trace widths, pad spacing, and via diameters. These limitations prevented direct soldering of some surface-mount components, prompting the addition of 8-pin female headers to accommodate commercial breakout modules (e.g., MPU6050 and battery monitor).

These issues will be corrected in a future PCB revision, which may be fabricated externally to allow for tighter tolerances, smaller geometries, and a reduced board area.

Figure 2 shows the fabricated PCB the prototype, that measures 58×60 mm and weights 80 g, and Figure 3 illustrates the top and bottom copper layers, including the continuous ground plane. The PCB is mounted on a lightweight headband and mechanically cushioned using foam material to improve comfort and maintain sensor alignment. The enclosure design also minimizes accidental torque forces in solder joints and ensures consistent placement during calibration.

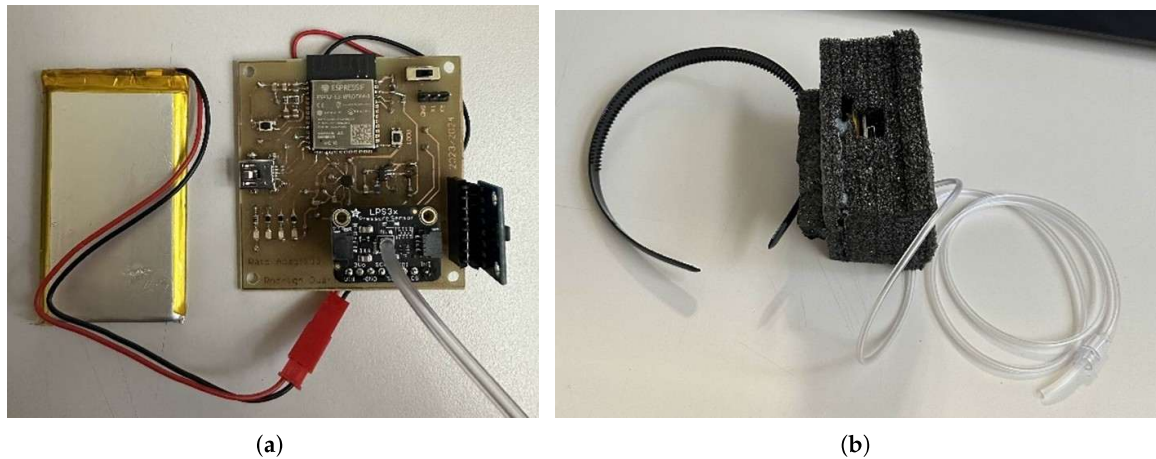


Figure 2. (a) Fabricated version of the PCB used in the prototype. (b) Prototype, in a rear view.

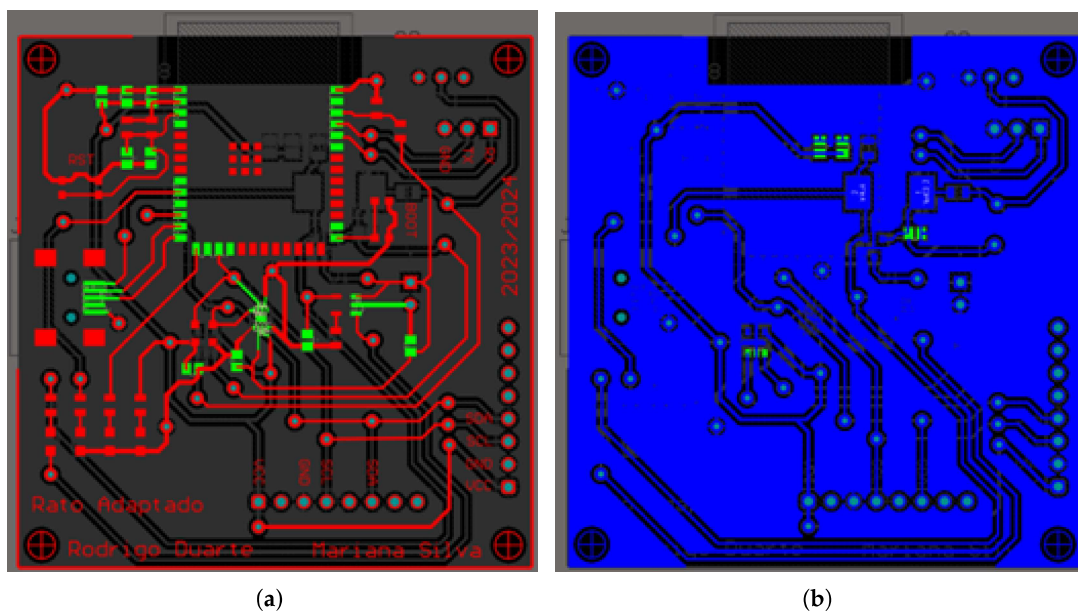


Figure 3. (a) Top layer of the custom-designed PCB. (b) Bottom layer of the PCB, including the ground plane.

5. Testing and Results

To validate the functionality and practical usability of the proposed assistive mouse, a series of functional, performance, and preliminary usability tests were conducted. The evaluation focused on responsiveness, calibration stability, robustness against unintended activation, and accessibility for users with reduced upper-limb mobility. Tests were performed in a controlled laboratory setting, with the user seated at a standard desk position approximately 60 cm from a 24-inch monitor under typical indoor lighting conditions.

5.1. Functional Testing

Initial functional tests verified the correct mapping between user gestures and mouse actions. Each input modality was evaluated in isolation, and gestures were repeated 20 times to assess consistency. Head movement was accurately translated into cursor displacement, with pitch controlling horizontal movement and roll controlling vertical displacement. Cursor motion was subjectively smooth, and no jitter was observed when the user held a static pose. Perceived latency was estimated to be below 100 ms, consistent with expected values for BLE HID communication.

Breath-based commands were evaluated using the integrated pressure sensor. Positive pressure (exhalation) triggered left-click events, while negative pressure (inhalation) generated right-click actions. Across 40 trials (20 inhalation, 20 exhalation), 38 were triggered correctly, resulting in an activation accuracy of 95%. No false activations occurred from passive breathing or speaking near the tube, indicating a stable threshold configuration. The system successfully established BLE HID pairing with Windows 11 without requiring additional drivers.

The results confirmed correct integration between sensing, processing logic, and wireless communication. Standard mouse actions, including dragging and double-clicking, were executed reliably during web browsing and file navigation tasks.

5.2. Preliminary Testing and Feedback

A preliminary validation session was conducted at ciTechCare—Center for Innovation in Health Technologies and Care (Polytechnic University of Leiria). The objective was to obtain clinically grounded feedback and assess ergonomic suitability before testing with end users who present motor impairments. An occupational therapy student with experience in assistive technologies and upper-limb rehabilitation supported testing. During the session, the prototype was worn and operated by a volunteer to evaluate positioning, comfort, and responsiveness in a realistic usage scenario, as illustrated in Figure 4.



Figure 4. Preliminary testing of head and breath interaction using the prototype.

Feedback highlighted the need to increase sensitivity to enable full cursor traversal with smaller head movements. Users with reduced cervical mobility may struggle to generate sufficient angular displacement with default parameters. Adjusting sensitivity thresholds mitigated this issue and reduced physical effort during extended sessions.

Calibration drift was observed when the device was not placed upright on a stable surface during initialization. When placed correctly on a flat surface (e.g., a table), drift remained below one pixel per second over a 10-minute period. This behavior underscores the importance of providing clear calibration instructions to the user.

Horizontal cursor control was initially configured using yaw-based tilting, which required lateral neck flexion. Instead, it was recommended to use pitch rotation, as turning the head is a more natural gesture that reduces muscle fatigue. This change also improved precision in edge-of-screen interactions.

The tests were performed using “KINKA Games”, a suite of therapeutic applications designed for cognitive and motor rehabilitation. These games provided real-time feedback on pointer accuracy and smoothness of movement, enabling an intuitive assessment of interaction quality.

For comparative purposes, the Quha Zono commercial head mouse was also evaluated during the session. Similar calibration drift was observed in this device, suggesting that drift is an inherent challenge in IMU-based systems. Notably, the commercial device required greater neck rotation to reach screen boundaries, implying a higher physical demand. The developed prototype, therefore, demonstrated competitive ergonomic advantages.

5.3. Extended Observations

Qualitative usability observations were collected during 20–30 min interaction sessions. Participants reported becoming proficient with breath-based click activation after approximately three minutes of familiarization, indicating a short learning curve. Head rotation gestures were perceived as comfortable throughout the testing and no cervical discomfort was reported.

The pressure sensor exhibited minimal sensitivity to ambient airflow, including from air conditioning systems, and no unintentional clicks were triggered during speaking. This robustness is essential for reliable operation in real-world environments. Additionally, BLE communication remained stable under typical office wireless traffic, and no disconnections were observed.

5.4. Limitations and Considerations

Although the prototype performed consistently during testing, several limitations remain. The system is sensitive to device orientation during calibration, and minor drift may occur if this procedure is performed incorrectly. Although sensitivity adjustments support diverse mobility profiles, determining optimal parameters may require iterative fine-tuning.

The current test cohort did not include end-users with motor impairments, which constitutes a methodological limitation. Long-term fatigue, comfort in wheelchair postures, and performance in activities of daily living have not yet been evaluated. Furthermore, breath-based input may not be suitable for users with respiratory limitations or tracheostomy.

5.5. Future Work

Future evaluation will include quantitative usability metrics (e.g., time-to-target, click accuracy), subjective comfort scoring, and fatigue assessment over extended sessions. A study with participants presenting real motor impairments is planned in collaboration with occupational therapists, along with an investigation of long-term reliability and battery life. Additional modalities, such as capacitive touch or adaptive gain control, can be integrated to support broader accessibility requirements.

6. Conclusions

This work presented the development of a low-cost head and breath-controlled assistive mouse designed to improve computer accessibility for users with motor impairments. The proposed device integrates an inertial measurement unit and a high-sensitivity pressure sensor on a compact, custom PCB, enabling full mouse control (cursor movement and click activation) via Bluetooth Low Energy (BLE) HID communication without requiring additional host-side software. By combining movement and selection within a single wearable solution, the system addresses a common limitation in existing commercial devices.

Functional testing demonstrated stable performance, smooth cursor motion, and accurate gesture detection, while preliminary expert feedback supported its applicability within assistive and rehabilitation contexts. A comparative evaluation against a commercial head mouse further highlighted ergonomic advantages, particularly reduced cervical effort and improved pointer reachability.

Despite these advantages, several limitations were identified. Cursor drift may occur if calibration is performed in non-upright orientations, and prolonged head gestures may cause fatigue for some users. In addition, breath-based activation may not be suitable for individuals with respiratory constraints. Future work will explore firmware-based calibration assistance, adaptive gain control, automated drift compensation, and alternative activation strategies to reduce user effort. Additional improvements to PCB integration and enclosure design could further decrease size and weight.

Overall, the results suggest that the proposed device provides an affordable, portable, and customizable alternative to existing assistive pointing technologies, particularly in resource-constrained environments. Planned future studies will include quantitative usability evaluations with end-users presenting real motor impairments, long-term fatigue assessment, and broader clinical validation. The modular architecture of the system also provides a foundation for integrating additional sensing modalities and supporting continued research in accessible human–computer interaction.

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Data Availability Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Abbreviations

The following abbreviations are used in this manuscript:

AT	Assistive Technologies
BLE	Bluetooth Low Energy
HID	Human Interface Device
IPC	Inter-Integrated Circuit
IMU	Inertial Measurement Unit
Li-Po	Lithium-Polymer Battery
PCB	Printed Circuit Board
USB	Universal Serial Bus

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